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And SYSCERA System in High-rise Buildings

SYSCERA © system, a new structural and technical construction system

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Synopsis

A new structural system and construction technology, called SYSCERA system, is introduced in the current study. SYSCERA system is a box type bearing wall system in which both gravitational and lateral loads are supported by interior and exterior SYSCERA walls.

SYSCERA wall is a concrete shear wall constructed by lightweight/low strength expanded polystyrene (EPS) concrete and reinforced with a 3D interconnected steel mesh, called a SYSCERA panel

Using a pre-validated numerical model, seismic performance of a 3-story residential building, constructed with SYCERA system, which is examined followed by required design procedure. Obtained results indicate that SYSCERA system, similar to other box-type structures, has-good seismic performance due to its high level of redundancy, lightness, and ductility of the used EPS concrete.

Keywords: SYSCERA®© system, lightweight concrete, EPS concrete, performance-based design, shear wall.

Key words: OriSTeeL®©, production line of metal structures used in construction, civil engineering and Public Works.

Keywords Ductility: property of a material to be easily deformed, and to be allowed to stretch easily. This is the main quality of the SYCERA concept.

Keywords Case I: construction with **SYSCERA**®© system

Keywords **Case II**; Construction with polystyrene walls sandwiched between two concrete sides.

Keywords **Case III**: construction in bricks of 20cm and mortar.

OriSTeeL®© is a brand name owned by Alain Blanck and filed at INPI, inventor of the SYSCERA construction concept, and inventor of OriSTeeL machines and tools, specially designed for manufacture in industrial quantities of the 3D metal **SYCERA**®© or **OriSTeeL**®©structures.

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1. Introduction

Nowadays, because of increasing population growth in the world, demand for more of these SYSCERA and OriSTeeL structures is inevitable. The structures have superior characteristics in terms of economic and technical points of view, especially in the case of high-volume construction.

Accordingly, innovative industrialised construction techniques are gaining more attention as they have many advantages over conventional construction methods.

In many industrialised modern construction techniques, columns and beams are replaced by bearing walls. In these box type systems, such as tunnel forms (Balkaya and Kalkan[1], Kalkan and Yuksel [2]), insulated concrete forms, ICF, etc., all walls are bearing walls which support both gravity and lateral loads. This study focused on a new emerging box-type system, called SYSCERA system.

SYSCERA system is a new type of structural system which uses SYSCERA walls to support both gravity and lateral loads. SYSCERA walls are concrete walls constructed by low strength/super-lightweight expanded polystyrene (EPS) concrete, reinforced by SYSCERA panels, SYSCERA beams and in some cases additional rebars. The SYSCERA panel is a three-dimensional galvanized steel mesh with straight and diagonal strips manufactured by a cutting-tensioning machine from a uniform steel plate, with no welding, as shown in Figure 1-a. The so-called strip has a rectangular cross section with thickness and width of 1.6mm and 5mm, respectively. SYSCERA beams (SYSCERA stiffener) are truss-like elements that pass through SYSCERA panels in both vertical and horizontal directions. A sample SYSCERA beam is illustrated in Figure 1-b. Its depth is 7 or 8cm and it includes five rebar with diameter of 4.5mm (two as top flange and two as bottom flange) and one diagonal rebar.

The SYSCERA stiffener sample is shown in Figure 1-b. Its width is 7 or 8 cm and it comprises five reinforcing bars with a diameter of 4.5 mm (two as a top flange and two as a lower flange) and a sinusoidal bar in the length.

(a) (b) (c)

Figure one. (a): SYSCERA Panel (b): SYSCERA stiffener in position, (c) stiffening plane.

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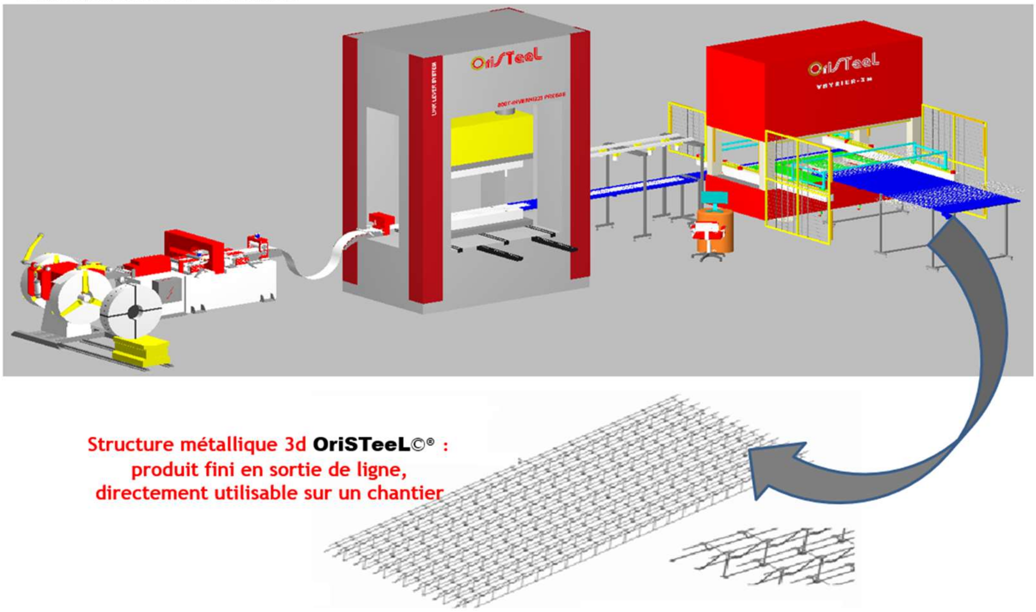
Représentation exacte d'une ligne de production OriSTeeL©®



Possible production from 4 to 5 pieces/MN on this line OriSTeeL. TD8 of 3M in length.

The main role of SYSCERA stiffeners is to make the SYSCERA panel stiff to ease the wall installation operation. Moreover, they can be considered as additional vertical and horizontal reinforcements. SYSCERA walls do not require formwork due to due to sticky nature of the used EPS concrete and closely spaced strips of the SYSCERA panel. Figure 2 shows the injection of EPS concrete into SYSCERA panel and finished surfaces of SYSCERA walls.

(a) (b) (c)

Figure 2. (a) EPS concrete injection (b) finished rough surface of the wall (c) finishing of walls syscera

Density of the used EPS concrete in SYSCERA system is about 1000 Kg/m3 and its compressive strength is about 5MPa. The interesting characteristics of SYSCERA system are its lightness and its high level of redundancy, such that for a typical 3-story residential building, the maximum compressive stress in walls of the first story would be less than 0.5 MPa under the service loads.

Such low stress level is also the case in box-type structures constructed with normal weight concretes as suggested by AIJ [3].

Current codes including ACI 318 [4] and Eurocode 8 [5] discourage using low strength concretes in structural elements, mainly due to durability concerns. In other words, current codes are not well suited for modern concretes as these codes assumed that required durability is accessible only through strength increasing while EPS or polymer-modified concretes can have superior durability with low strength. However, some standards such as AC 408 [6] recognized above characteristics and imposed no limitation on compressive strength of structural EPS concrete.

The main objective of the current study is to evaluate structural usage of low strength EPS concrete. There is a significant difference between lean concretes and low strength concretes. A lean concrete is porous and brittle. However, as suggested in earlier studies, EPS concrete is very ductile and quite durable. More comprehensive discussion about EPS concrete can be found elsewhere in this document. (Babu et al [7]; Babu et al [8]; Chen and Liu [9]).

2. Cyclic behavior of SYSCERA wall

It is well-understood that a nonlinear analysis would fail to give reliable results if the assumptions made behind it were unreliable.

The most important question that the designer should ask him/herself, is "Am I using the correct data for the EPS concrete behavior?"

It is obvious that stress-strain curve of the EPS concrete, or any concrete in general, strictly depends upon its mix proportion. For the mix proportion of Table 2, the stress-strain curve is illustrated in Figure 3. Behaviour of the concrete is also simulated in the general-purpose finite element program, Abaqus [10], using the well-known damaged plasticity model. Note that crushing strain of the used EPS concrete is about three times greater than that of normal weight concrete. In other words, the used EPS concrete can sustain larger strains and subsequently larger deformations.

Table 1. Considered mix proportion for the EPS concrete

Cement	Water	Sand powder	*EPS beads*	*Glass fiber*	*Wet density*	*Dry density*	*Average compressive strength (MPa)-*
(Kg)	(Kg)	(Kg)	(Kg)	(Kg)	(Kg / m3	(Kg / m3)	33 jours
515	240	380	13.2	5.6	1155	1043	5.5

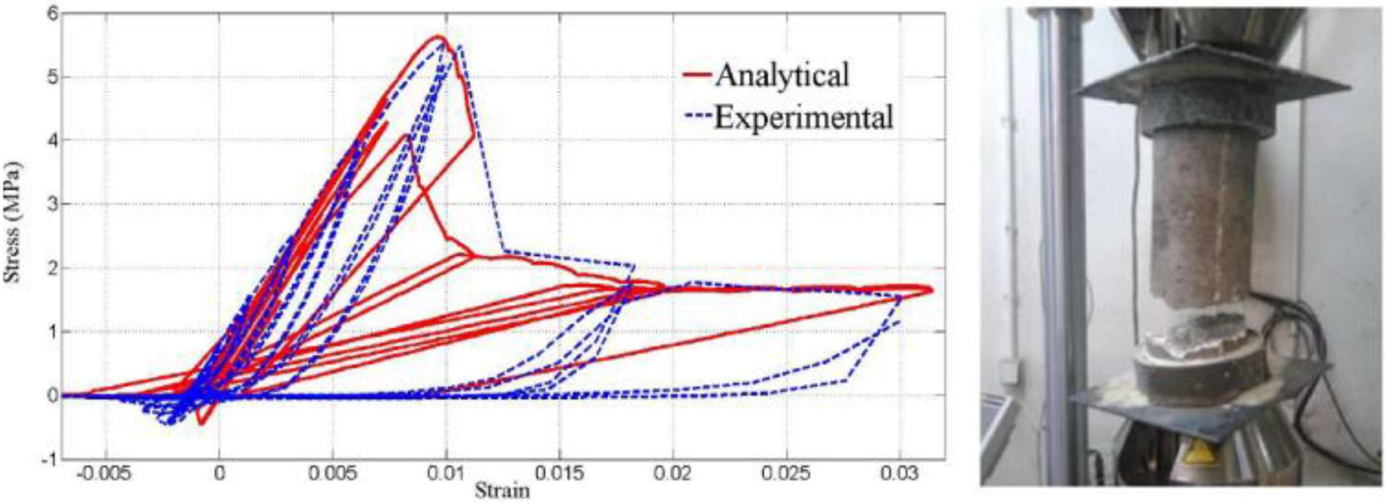


Figure 3. Cyclic behavior of a sample of a test cylinder of EPS concrete

Cyclic behaviour of SYSCERA walls have been evaluated experimentally and numerically by Mousavi et al [11] and Mousavi and Bahrami-Rad [12]. Abaqus can reliably estimate developed behaviour of SYSCERA walls, as depicted in Figure 4. However, it cannot accurately simulate the behavior of SYSCERA wall, or in general any concrete wall, under cyclic loading mainly due to the pinching effect.

As depicted in Figure 7, IDARC [13] can accurately estimate behaviour of SYSCERA walls under reversed loading conditions.

In other words, if the SYSCERA structure is going to be designed according to some historical analysis, IDARC should be used to model the building. However, simulation with IDARC needs some previously calibrated parameters that are not currently available for different SYSCERA walls with different aspect ratios and reinforcement details.

As design of the SYSCERA system would be performance based with monotonic loadings, Abaqus' results would be satisfactory.

Note that cyclic degradations are also accounted in the derived numerical model. SYSCERA panels and SYSCERA stiffeners can be modelled explicitly or as equivalent closely spaced rebars.

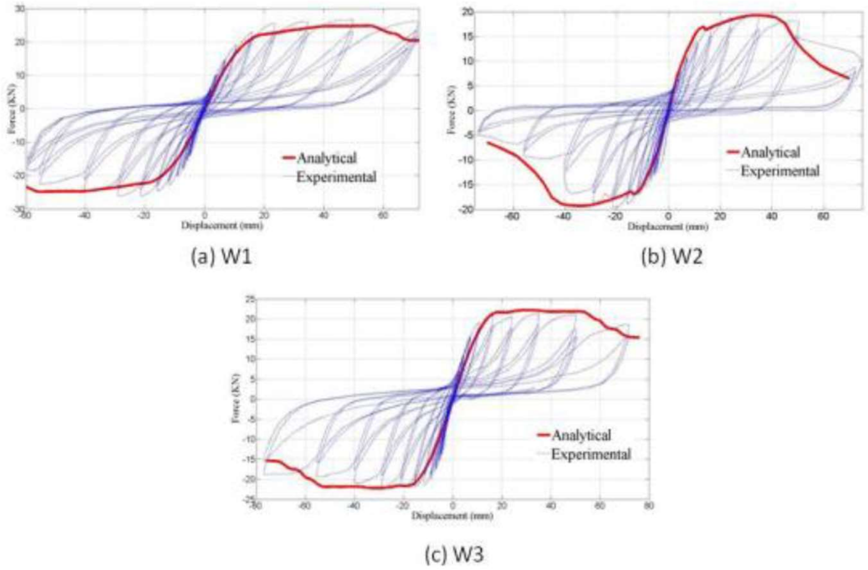


Figure 4. Reliability of the model in Abaqus under monotonic loading, Mousavi et al [11]

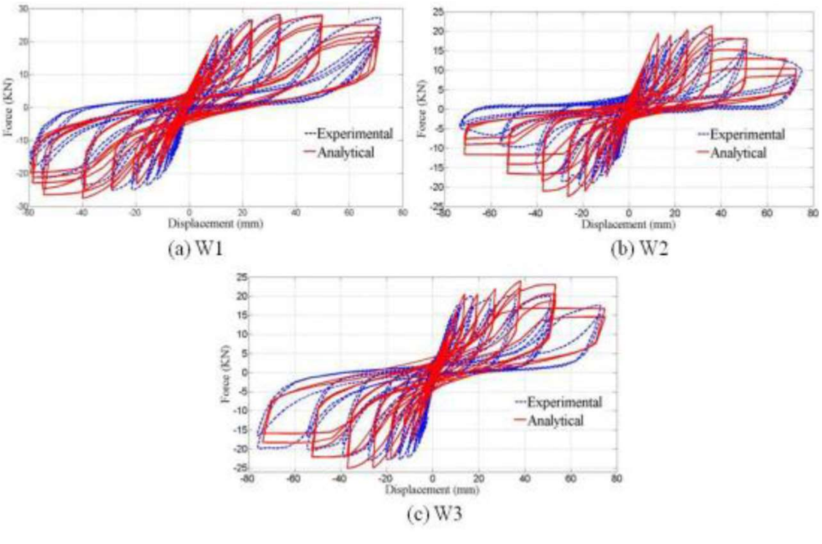


Figure 5. Reliability of the model in IDARC under cyclic loading, Mousavi et al [11] 3.

3. Design procedure of SYSCERA system

Proposed design procedure for the SYSCERA system includes two separate phases, namely preliminary and final phases. Detailed steps for each phase are presented through designing a 3-story residential building that is currently under construction at Kerman.

The building is designed according to the highest seismicity of the country according to the Iranian seismic code [14]. Two-way flat slab with normal weight concrete is considered for all floors.

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3.1. Preliminary design

Preliminary analysis and design of the SYSCERA system, which is linear elastic, is just like conventional systems. The building would be modelled in SAP [15] or ETABS [16] or other conventional analytical software in which shell elements can be modelled in a 3D space. In this phase of the job, there is no need to model nonlinear shells or carrying out nonlinear analysis. It is recommended to use multilayered shell elements rather than homogenous ones. The software SAP, for example, can be used to model multilayered shell elements.

Gravity and lateral loading is just like other systems however the following points should be respected.

1. The modification factor (R) is 5 for this system, per ASCE7-05 [17] for similar systems. This parameter is only required in this phase of the design and note that at the final design phase there is no need to apply a modification factor due to the fact that the final phase would be nonlinear.
2. Wind loading should be also considered as the SYSCERA system is very lightweight and, in some cases, lateral loads could be dominated by wind rather than earthquake.

The main goals of this phase are, firstly to have a general understanding about behavior of the building and its compressive/tensile stresses that are developed at different parts of the structure, and secondly, to obtain required dynamic characteristics of the structure, such as its natural frequencies, modal participation factors, modal vectors, etc. Note that this data would be required at the final phase of the design.

In addition, from the preliminary design other important features of the structure would be also revealed, such as its level of torsional irregularity, rigidity level of horizontal diaphragms, etc. Adopted 3-story building is modelled in ETABS which is very popular amongst Iranian engineers. Floor dead and live loads of the building are 450 and 200 Kg/m2, respectively (1Kg ≈ 10N).

Stress contour on the vertical direction is shown in Figure 6. Such contours give a useful impression about the level of stresses at different regions. For example, in this figure the maximum compressive strength is about 0.7MPa under ultimate gravity loads, i.e.

1.2D+1.6L. Besides, such contours can be used to validate other models of the building, for example constructed model in Abaqus. Main features of the building are summarized at Table 2.

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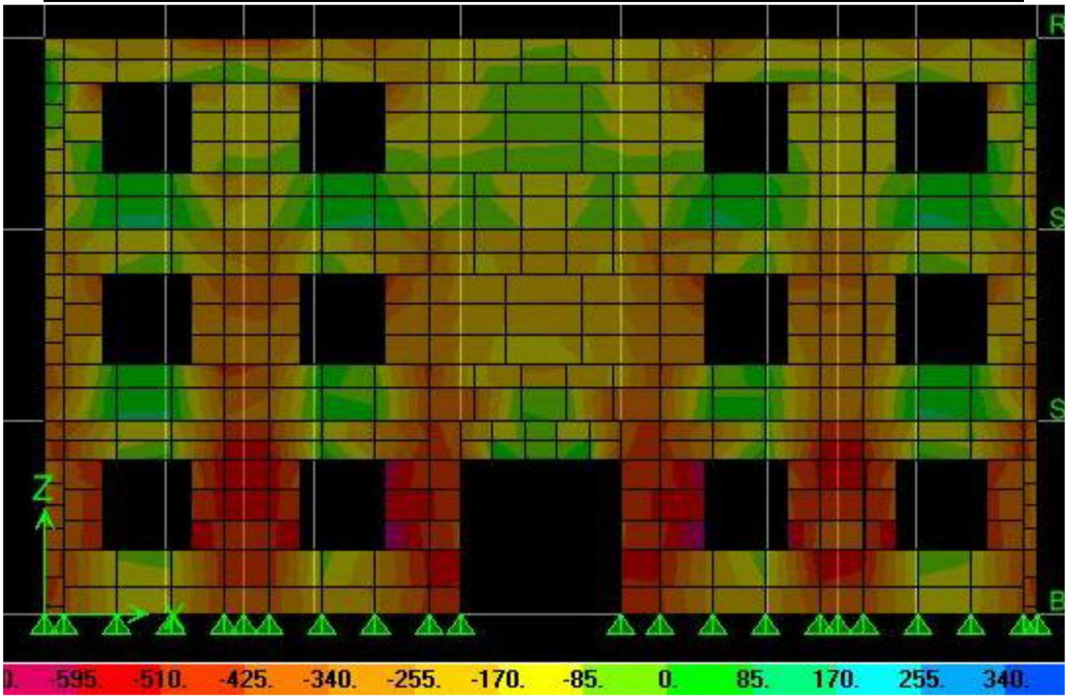

Figure 6. Stress contour at the preliminary design phase

Table 2. Main characteristics of the building

Total dead load	*Total live load*	*First period (s)*	*Second period (s)*	*First modal mass participation*	*Second modal mass participation*
En tonnes	En tonnes				
428	98	038	029	87%	82%

The first and second modes of the building are, respectively, on the X and Y directions. In obtaining periods of the building, no reduction factor should be used due to cracking. Because these periods are going to be used at the final phase in which initial elastic periods are needed.

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3.2. Final design

After the preliminary design, the designer will have gained a general impression about the structure and its overall behaviour.

The adopted building is modelled in Abaqus and subjected to 1.2D+0.5L as its gravity loads. This is done using a separate static step.

For the lateral load, another dynamic implicit step is defined. Lateral loads are distributed according to the first modal vector in each direction. At least two lateral load distributions should be considered, per FEMA 356 [18]. However, here only the aforementioned distribution is considered due to space limitations.

Acceptance criteria of SYSCERA walls differ with those reported in FEMA 356. Strain-based acceptance criteria, extracted based on experimental results, as reported by Mousavi et al [11] would be used for SYSCERA walls. Recommended strains are presented in Table 3. Again, it should be noted that these values are obtained exclusively for the mix proportion of the used EPS concrete.

Table 3. Acceptance criteria for SYSCERA system

	IO	LS	CP
Principal compressive strain	0,003	0,007	0,01
Main deformation in traction	0,02	0,05	0,08

If some regions of the building fail to satisfy these criteria, those regions need to be strengthened. This can be done using additional rebars, increasing wall thickness, increasing concrete strength, etc.

Three cases are considered for this building, as presented in Table 4. Default reinforcement of SYSCERA walls, in this paper, are SYSCERA panels plus vertical SYSCERA stiffeners per 100cm and horizontal SYSCERA stiffeners per 100cm.

Table 4. Different cases considered for the 3 level building.

Case	Description
I	*No-additional rebar, lateral load at X-direction*
II	*No-additional rebar, lateral load at Y-direction*
III	*Additional horizontal rebar (Φ8 @ 50cm), lateral load at X-direction*

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Case 1- (SYSCERA)

Pushover curve of the building in this case and its damaged states for different performances is depicted in Figure 7. In this paper, zones that have surpassed acceptance criteria are highlighted with white colour. The target displacement can be found as follow, per FEMA 356.

$$\delta_t = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2} g = 1.3\times1.1\times1\times1\times0.96\times\frac{T_e^2}{4\pi^2}\times9.81 = 0.34T_e^2 \quad (1)$$
$$T_e \approx T_0 = 0.38s \rightarrow \delta_t = 0.34\times0.37^2 = 0.049 = 49mm$$

According to Figure 7, exterior walls of the building at x-direction and at the first story need to have more shear capacity as diagonal damages which indicate diagonal cracks have appeared on these regions according to LS performance criteria.

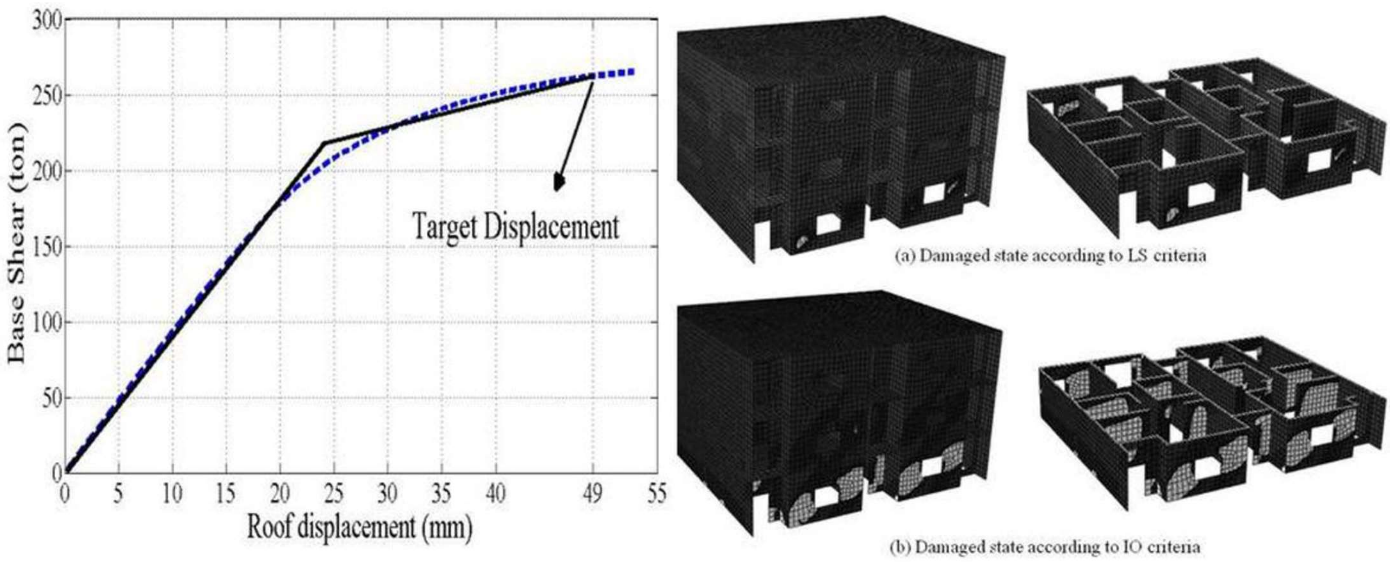

Figure 7. Pushover (capacity) curve of the building and its damaged states per LS and IO criteria in case *I* (1 ton=10KN)

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Case II

Target displacement in this case can be estimated as follows.

$$\delta_t = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2} g = 1.3\times1.1\times1\times1\times0.96\times\frac{T_e^2}{4\pi^2}\times9.81 = 0.34T_e^2 \qquad (2)$$
$$T_e \approx T_0 = 0.29s \rightarrow \delta_t = 0.34\times0.29^2 = 0.029 = 29mm$$

Again, in this case, pushover curve and damaged states of the building is illustrated in Figure 8.

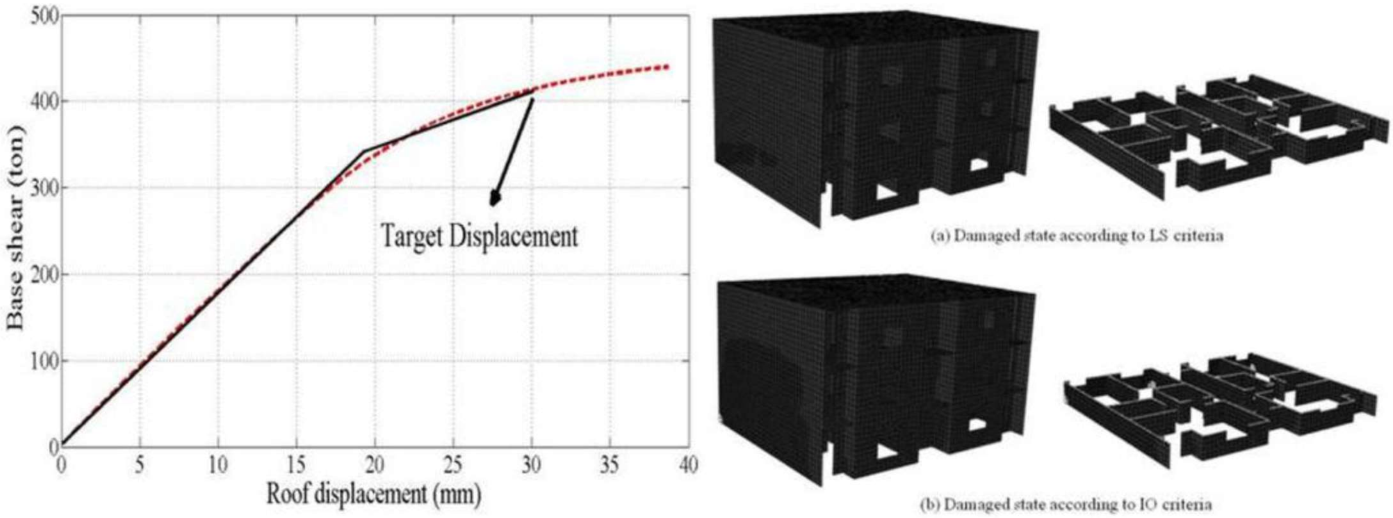

Figure 8. Pushover (capacity) curve of the building and its damaged states per LS and IO criteria in case *II*

(1 ton=10KN)

Note that stiffness of the building in X and Y directions from Figures 7 and 8 can be estimated as,

$$K_x = 9.2\ ton/mm,\ K_y = 17.6\ ton/mm,\ \frac{T_x}{T_y} = \sqrt{\frac{K_y}{K_x}} = \sqrt{\frac{17.6}{9.2}} = 1.38 \qquad (3)$$

Above ratio according to ETBAS, presented in Table 2, is 1.28. Obtained stiffness ratios, validate both models to some extent and such comparisons are highly recommended. The small difference between obtained ratios root to the fact that obtained stiffness from ETABS is initial stiffness while that obtained from Abaqus is effective stiffness.

It is clear that on this direction, the building would satisfy LS performance criteria. If IO performance is required, SYSCERA wall need some additional reinforcements on highlighted regions.

Case III

As stated in Case I, some additional rebars need to be implemented into the building in X direction, especially at its first story. The pushover curve and damage states of the building are illustrated in Figure 9. It is clear that in this case LS acceptance criteria would be satisfied.

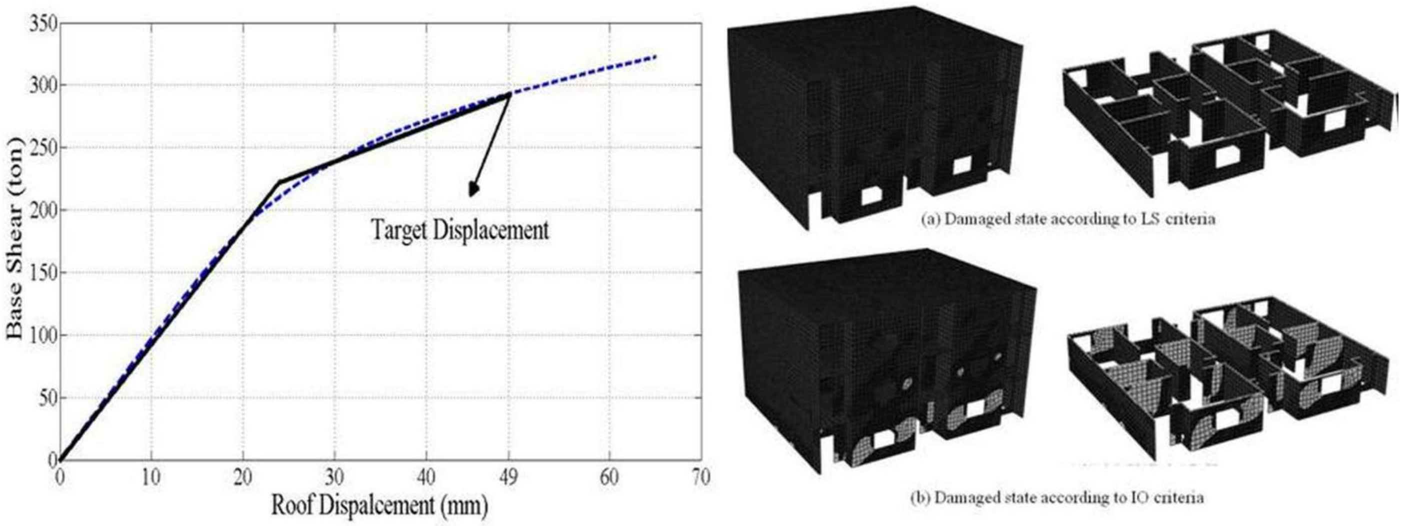

Figure 9. Pushover (capacity) curve of the building and its damaged states per LS and IO criteria in case *III*

(1 ton=10KN)

Finally, the authors would like to elaborate that an accurate computer model and a well-designed building would not necessarily guarantee to have a reliable building. Special care should be paid on construction phase, especially for the following items; Mix proportion of the EPS concrete, out-of-plumbness of SYSCERA walls, concrete curing, additional rebars (if any), and development length of SYSCERA panels, SYSCERA stiffeners and rebars.

3.Conclusions

A new emerging structural system and construction technique, called SYSCERA system, is introduced in this paper. SYSCERA system is a box-type structure in which SYSCERA walls would carry both gravity and lateral loads. According to experimental and numerical studies, it has been found that SYSCERA walls have high level of ductility due to their used EPS concrete and SYSCERA panels which provide a well-detailed reinforcement for the wall. This fact is again observed in this study during system-level simulation of a 3-story building. Design procedure of the SYSCERA system including two preliminary and final phases is proposed and required steps in each phase are discussed during the paper. This study shows that a low strength EPS concretes can be used in structural elements and perform quite well.

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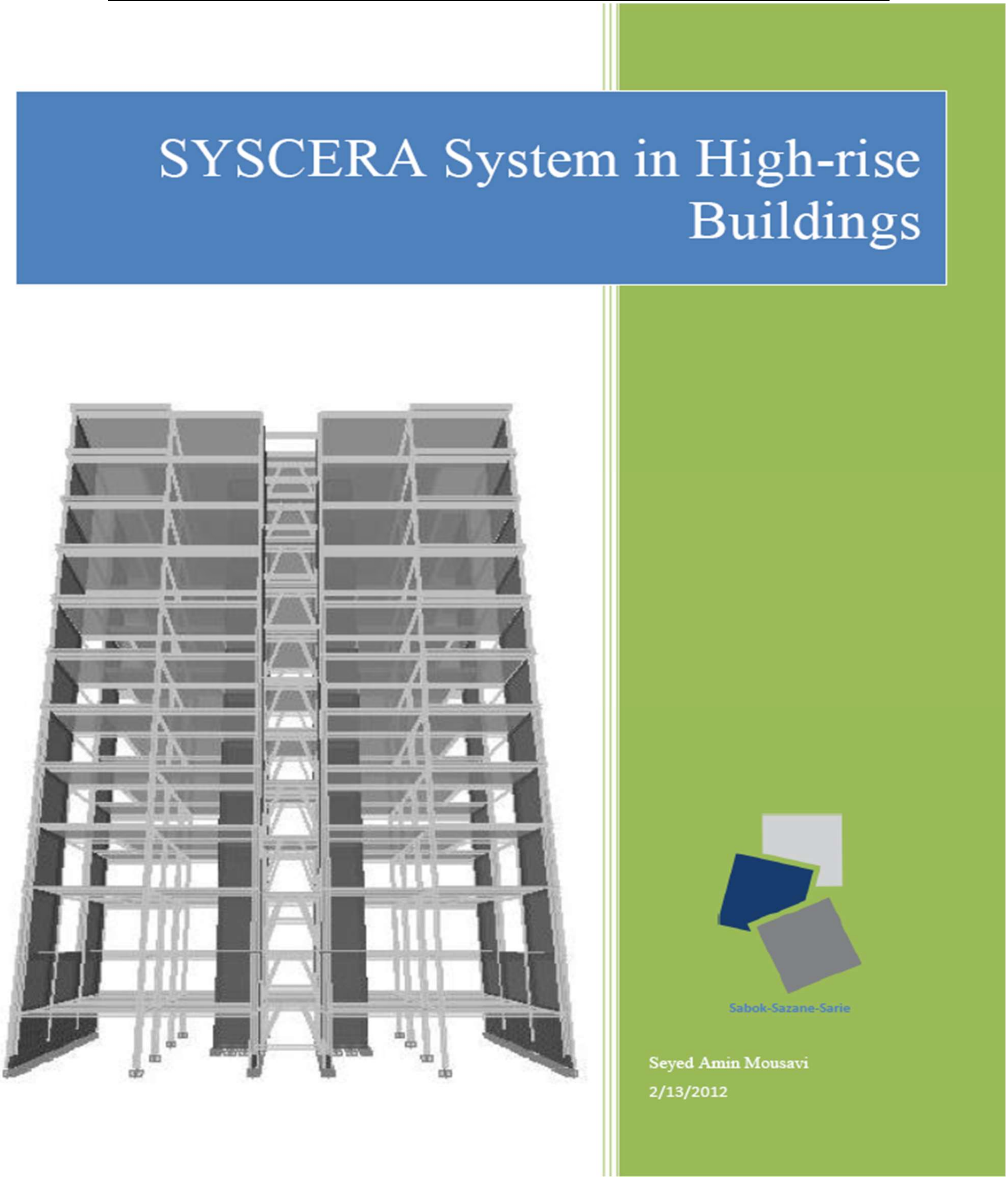

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SYSCERA System in Combination with Framed High-rise Buildings

Technical & Economical Features

By: Seyed Amin Mousavi,

INTRODUCTION

It is well understood that SYSCERA walls provide a reliable structural system due to its high ductility and high redundancy.

SYSCERA system, however, can be used in combination with other structural systems. SYSCERA walls and floors have two important effects on the structure they have implemented. First, they noticeably decrease dead load of the structure, and second, they enhance energy dissipating capacity of the structure, just like dampers.

The first effect of SYSCERA system, i.e. lightness, can be seen in other systems, such as 3D panel, hollow bricks, etc.

However, the second contribution cannot be seen in other systems, except in 3D panel to some extent. Because brick walls are assembled from many discrete brittle units, bricks, that behaves in a brittle manner. 3D panels are composed from two very thin concrete layers which they are partially composite through some diagonal truss-like rebars. However, their conventional reinforcement scheme, i.e. vertical and horizontal rebars, and also their normal weight concrete imposes some limitation on their ductility.

The intention of the current manuscript is to evaluate effect of reduced dead load of a building due to presence of SYSCERA wall and SYSCERA floor rather than conventional wall and flooring systems. Effect of load bearing capacity and ductility of SYSCERA walls are not considered in this study. They would be examined in another study.

And SYSCERA System in High-rise Buildings

Sorak project is a 12-story residential building with the following architectural drawings, Figures 1 to 3.

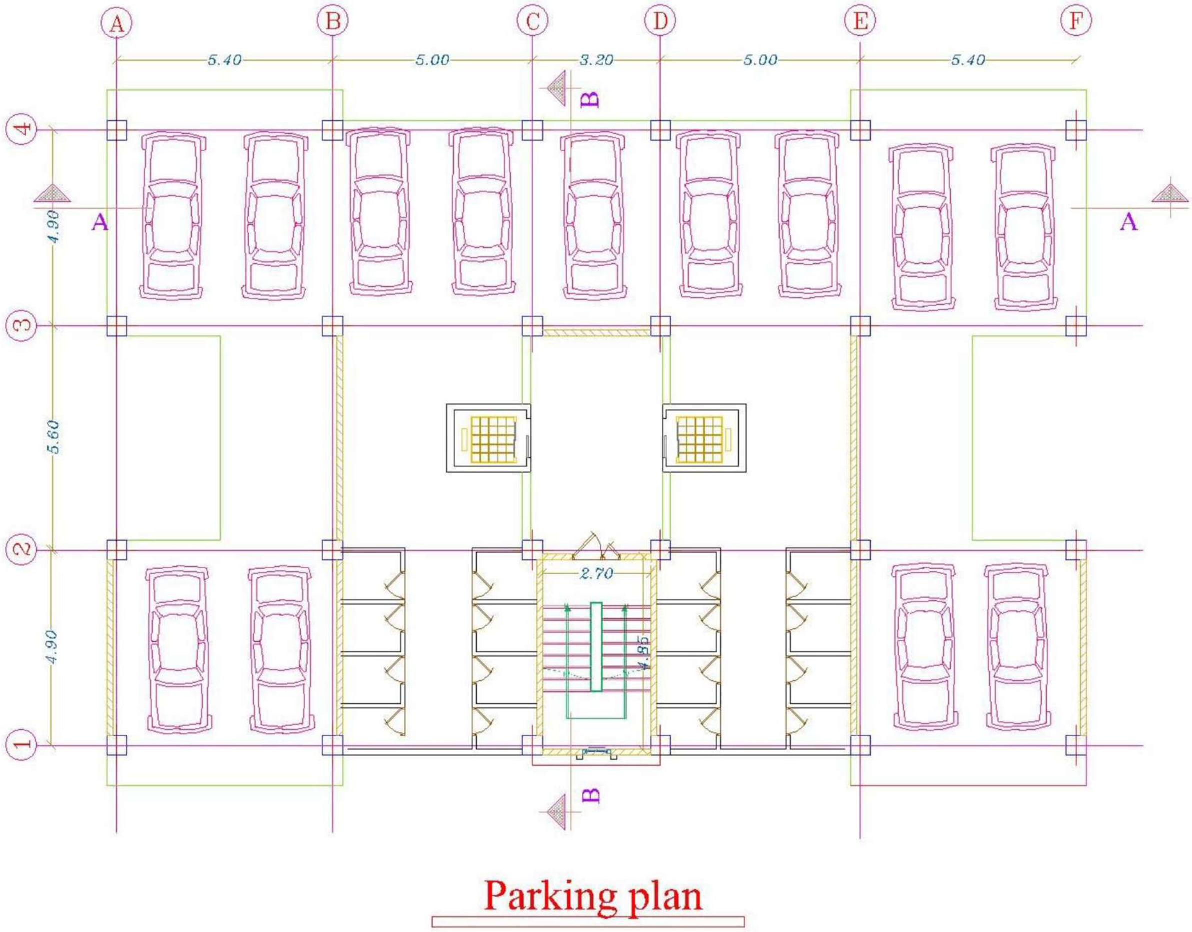

Figure 1. Parking plan

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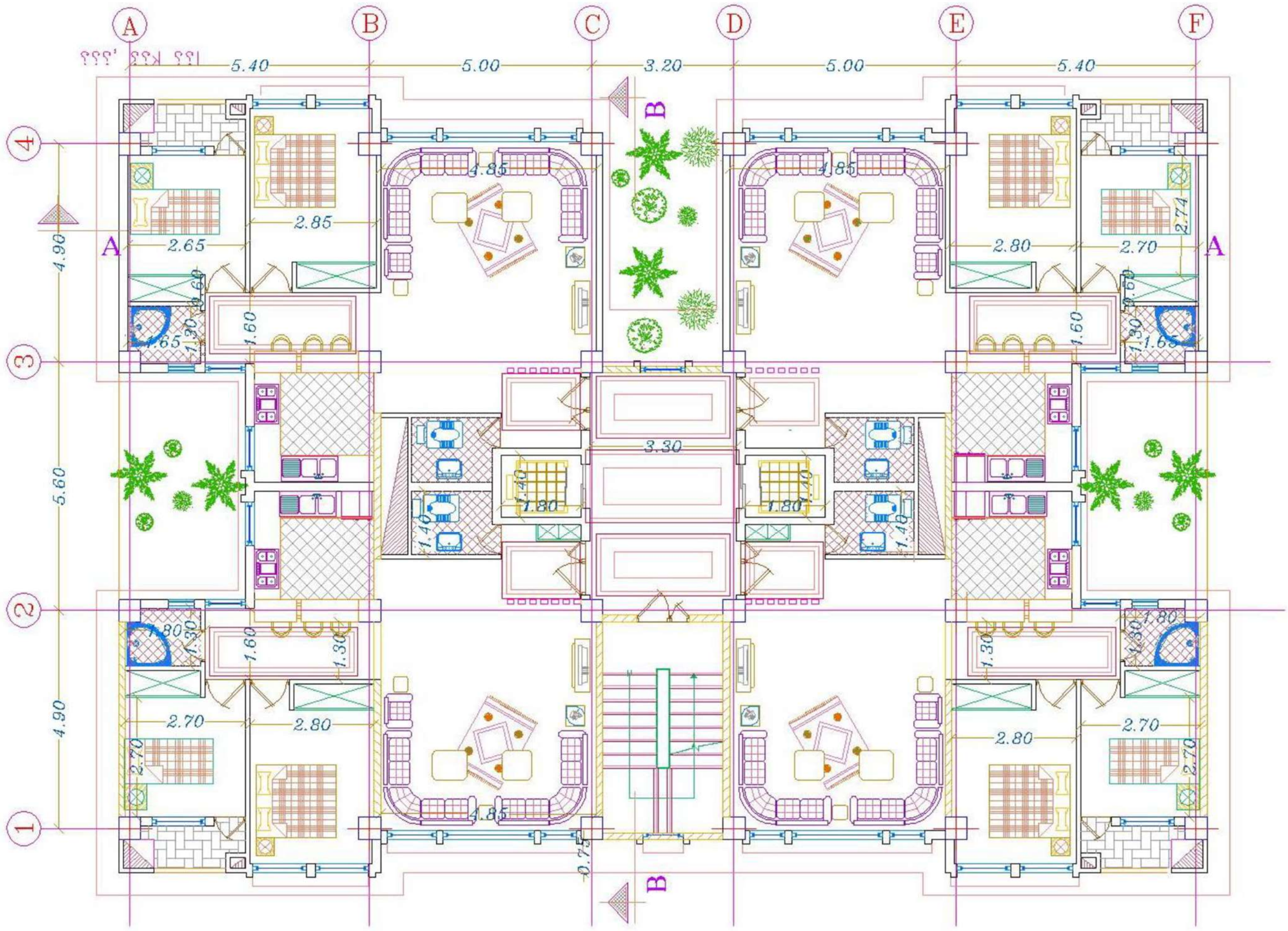

Residential stories typical plan

Figure 2. Typical stories plan

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Figure 3. Different sections of the building

Three different cases are considered in this study as represented in Table1 and illustrated in Figure4. Densities of concrete, EPS concrete, and mortar are assumed to be 2200, 800, and 1600 Kg/m3, respectively.

Table 1. Considered walls and floor systems

	Wall	floor	wall load (Kg/m^2)	floor load (Kg/m^2)
Case I	SYSCERA -12cm	Mini-beam	96	100
Case II	3D panel-12cm	3D panel	105	182
Case III	Earthen hollow bricks-20cm	joist-block	170	200

Details of the 3 compared systems

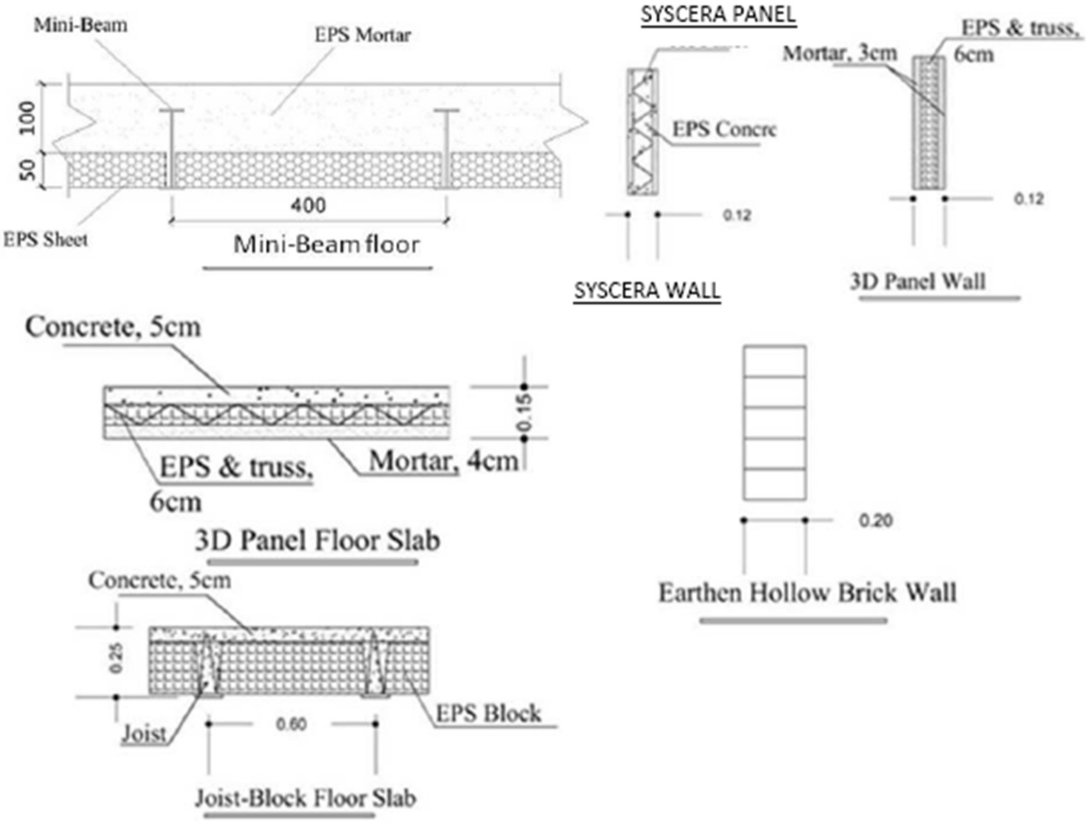

Figure 4. Considered wall and floor systems

It should be noted that 70Kg/m2 is added to all floor dead loads, 70Kg/m2 for exterior walls, and 50Kg/m2 for interior walls, to accounts effect of finishing. Moreover, effect of interior walls is considered in gravity loads of the floors.

Length of interior walls in residential stories is about 130m. Multiplying this value with net height of residential stories (3m), area of interior walls would be 390 m2. Dividing total weight of all interior walls in one floor by area of the floor plan (365m2, regardless of staircase), one can estimate the value that should be added in dead load of the floor.

$$\text{Equivalent surface load of interior walls} = \frac{390 \times weight\ of\ interior\ wall(\frac{Kg}{m^2})}{350}$$

It should be noted that for parking floor there is no wall but because of higher finishing weight, equivalent interior walls are considered for this floor too.

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Table 2. Dead load of each case

	Exterior walls (Kg/m)	floor load (Kg/m^2)	Equivalent interior wall loads (Kg/m^2)	floor load considering effect of interior walls (Kg/m^2)	Floor's live load (Kg/m2)
Case I	510	170	105	275	200
Case II	540	230	115	345	200
Case III	745	250	190	440	200

Due to the high openings in some exterior walls, a reduction coefficient of 0.5 is considered for their wall loads. Besides, live load of parking floor and corridors are assumed to be 500 and 350 Kg/m2, respectively. It should be noted that stair head room is not modeled and its weight would not directly considered. Instead, however, live load of the roof is assumed to be 200Kg/m2 rather than 150 Kg/m2.

Comparison between Standard No. 2800 and ASCE7-05 for moment frame system

Standard No. 2800

The building is located in Mazandaran, North of Iran. According to Standard No. 2800,

$$C = \frac{ABI}{R}$$

where « C » is the seismic coefficient, « R » represents behaviour factor (or response modification factor), « A », « B », and « I » stand for design acceleration, response spectrum value, and importance factor of the building, respectively.

According to location of the building,

A = 0,3

Shear wave velocity of the site is assumed to be 350m/s, therefore according to Standard No. 2800, soil type of the site would be type III. Accordingly, above parameters depend upon soil type and seismicity of the site.

Using approximate value for T,

T_0=0.15

T_s=0.7

S=1.75

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Above parameters depend upon soil type and seismicity of the site.

Using approximate value for T,,

$$T = 0.08H^{0.75} = 0.08 \times 35.1^{0.75} = 1.15s$$

Height of the building is measured from ground rather than base of the building.

According to Standard No. 2800, it is allowable to increase this value by 25% therefore,

T=1.44s

$$B = (s+1)\left(\frac{T_s}{T}\right)^{0.67} = 2.75 \times \left(\frac{0.7}{1.44}\right)^{0.67} = 1.70$$

According to Standard No. 2800 for this building Intermediate steel moment frame is allowable. For this System

R = 7

Therefore,

$$C = \frac{0.3 \times 1.70 \times 1}{7} = 0.073$$

,

The above value for seismic coefficient is applicable for allowable stress design. In order to transform it into the LRFD design, it should be multiplied by 1.4.

Therefore,

C_{LRFD}= 1.4 C_{ASD}=1.4×0.073=1.102

ASCE7-05

According to definition of different parameters in ASCE7-05 and Standard No. 2800,

$$S_{DS}=AB_{max}=A(s+1) = 0.3\times2.75=0.825$$

$$S_{D1} = \frac{T_0 S_{DS}}{0.2} = \frac{0.15 \times 0.825}{0.2} = 0.62$$

According to Table 11.6-1 of ASCE7-05 the seismic design category of the building is “D”.

According to Table 12.2-1, intermediate moment frame is not permissible for this building, therefore special moment frame should be used with R=8.

According to Sec. 12.8 of ASCE7-05,

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I}\right)} = \frac{0.825}{8} = 0.103$$

It is obvious that both Standard No.2800 and ASCE7 lead to a unique value for the seismic coefficient. However according to ASCE7, this building should be proportioned and detailed according to special moment frame provisions while an intermediate moment frame is acceptable according to Standard No.2800's point of view. In other words.

Due to the fact that many provisions of Iranian codes are mainly based on American codes of practice, like AISC, ACI, FEMA, etc. and many American codes, excluding FEMA, are mainly prepared according to ASCE7, it is more reasonable to consider ASCE7 loading rather than Standard No.2800. Accordingly, this manuscript is prepared based on ASCE7-05 loading provisions.

For this building a response spectrum analysis is adopted.

Acceleration spectrum is obtained based on ASCE7-05 modified by Mazandaran region divided by R/I.

According to 11.4.2 (or able 20.3-1), site class of the building is “D”, i.e. stiff soil.

Required parameters for response spectrum is

S1=0.62
Ss= 1.225

According to procedure presented in Sec. 11.4.5 of ASCE7-05, the pseudo acceleration spectrum for Mazandaran region is illustrated in Fingure5.

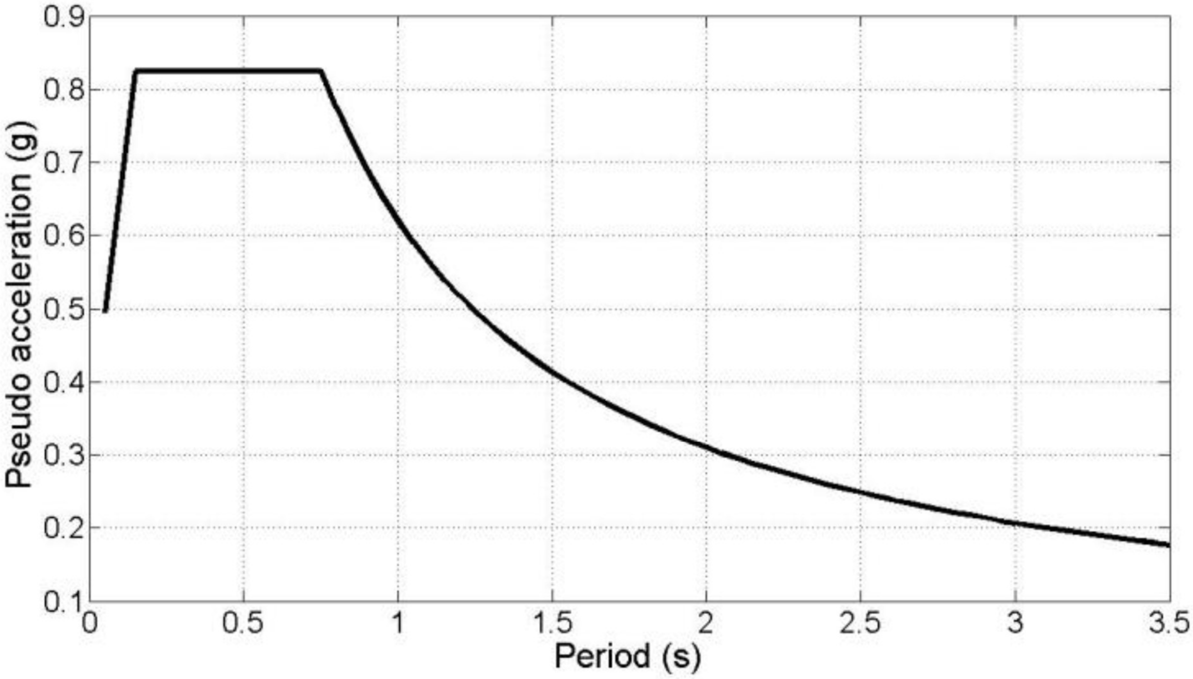

Figure 5. Modified acceleration spectrum for Mazandaran

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Partition wall as a shear wall & infilled wall

If a partition wall be able to transfer lateral loads, it would behave as a shear wall during a seismic event. Such as wall called shear-partition wall in this manuscript. Therefore, a shear-partition wall should satisfy two requirements. First it should be ductile enough to sustain seismic-induced lateral displacements and, second, its connections (connection to beam, column, ground, and floor slab) should be strong enough to be able to transfer all imposed loads.

Case I- SYSCERA :

SYSCERA wall: SYSCERA walls can be considered as shear walls because their high ductility thanks to their novel reinforcement technique (SYSCERA panels). Moreover, it is possible to design their connection as force-controlled components. Infilled SYSCERA wall can also effectively increases capacity of its corresponding frame.

Case II :

3D Panel wall: 3D panels actually are composed of two slender concrete walls partially composited by diagonal truss like meshes passed through polystyrene panel (or core). Their ability to sustain lateral, or even gravity, loads strictly depends upon diagonal meshes which connect two slender layers together.

Case III :

Hollow brick walls: this wall cannot be considered as a shear wall because it has a low strength and low level of ductility (actually no ductility). Specially due to the fact that hollow brick tiles are weaker than their mortars and they would behave similar to a force controlled element as suggested by FEMA306 (Sec. 8.2). The author would like to elaborate that it is possible to consider hollow brick walls as infilled walls, but this is not an economical decision because in this case the designer have to use modification factor for hollow brick walls (is about 1.5 according to ASCE7) in analysis procedure. In other words, if the designer considers effect of these walls in structural analysis, he/she have to design the building virtually elastic that significantly increases project costs.

According to FEMA306, however, clay bricks have relatively moderate level of ductility. But the main drawback of clay bricks is their weight which dramatically increases total weight of the building.

Concretes weaker than minimum strength accepted by ACI

According to ACI318-08 (Sec. 5.1.1), the concrete compressive strength should not be less than 2500psi (17MPa). The intention of ACI for this limitation is to provide a durable and ductile concrete. Besides, many provisions of ACI are based on earlier researches carried on using high strength concrete.

But what if it is possible to have a durable and ductile concrete with strength less than 2500psi?

ACI answers this question on its Sec. 1.4. ACI in this section approves new materials which do not conform to the Code if their sponsors can show their efficiency through successful use, or by analysis or test.

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The author would like to elaborate that SYSCERA walls that use EPS concrete (with compression strength of about 6 MPa) have shown quite ductile behaviour under in-plane monotonic lateral loading. These analyses have been ca ried out using Abaqus finite element package. Discussion of obtained results is out of scope of the current manuscript. However, obtained results indicate that according to ACI318-08, SYSCERA walls can be used as special shear walls.

Analysis procedure selection:

According to Sec.12.6 of ASCE7-05, Modal response spectrum or seismic response history techniques should be used for this building.

According to FEMA273 (chapter2), linear or nonlinear dynamic analysis should be performed for this building. It should be noted that static linear procedure is not allowable due to height of the building (larger than 100ft), and nonlinear static procedure is also not permitted because of important effects of higher modes.

Effect of infills in steel frames:

Effect of infills on structural frames is not a well-documented subject. Some codes, however, have some provisions about it, such as FEMA273 and its commentary FEMA274.

According to FEMA 356, infill walls and frames should be considered to carry seismic lateral forces in composite action, until complete failure of the walls. In the case of brittle infills, the wall should be removed from analytical model. It should be noted that a wall would fail if it does not satisfy acceptance criteria of chapter 6 (for concrete infills) and chapter 7 (for masonry infills).

Brittle infills can lead to significant torsional irregularity. Accordingly, it is more reasonable to detail brittle infills such that they can be labelled as isolated infills (infills that have no interaction with its surrounding frame).

According to Eurocode8 (Sec. 6.10.3), infills can be categorized into three types:

1. Infills that are positively connected to the structural frame: these infilled frames should be designed using chapter7 of Eurocode8 or according to AISCm part II.
2. Infills that are structurally disconnected from surrounding frame on the lateral and top sides (isolated infills): these infilled frames should be analysed regardless of effects of the infill.
1. Infills that are connected to its surrounding frame but not with positive connections: these infilled frames can be designed using the compression strut concept or using Gap elements (elements that can transfer only compression forces).

In this manuscript effect of infills are considered only for Case I (SYSCERA walls) due to their high ductility.

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Modeling :

The building is modelled using ETABS V 9.7.0. All steel structural elements are designed using AISC360-05 and seismic provision of AISC341-05. All concrete structural elements are designed using ACI 318-08 or results obtained from analytical models (for SYSCERA walls).

All beams and columns are considered to be frame elements (linear strain in their cross section) and all walls are modelled using shell element to capture nonlinear strain in their cross sections.

Design of foundations and slabs are out of scope of this manuscript. It is clear that some cast-in-place piles would be helpful, or even necessary, for the foundation of this building.

Floor slab for case II is a two-way slab and for cases I and III is a one-way slab.

Partition walls are all neglected in the model, however their weights are considered in the floor dead load. This means that they should be constructed after their floor construction and their connections to structural elements should be designed according to service level, rather than design level, earthquake.

As stated earlier, infilled walls are modelled only in Case I, i.e. SYSCERA walls. Because other walls, i.e. 3D panels with thin concrete layer and hollow brick walls, are too brittle to be considered as structural infills in the mathematical model.

It is interesting to note that 3D panel walls can be considered as structural walls if their concrete layers have a min mum thickness of 5cm and also the panel has well detailed diagonal elements. However, such a wall would increase dead load of the building. This claim will be more discussed later in this manuscript.

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Modelling of infill panels :

Frames with SYSCERA infilled walls can be categorised as Special Reinforced Concrete Shear Walls Composite with Structural Steel Elements (C-SRCW) as defined in many codes of practice such as AISC, FEMA356, Eurocode8, ASCE7, etc.

Schematic illustration of this system is shown in Figure 6.

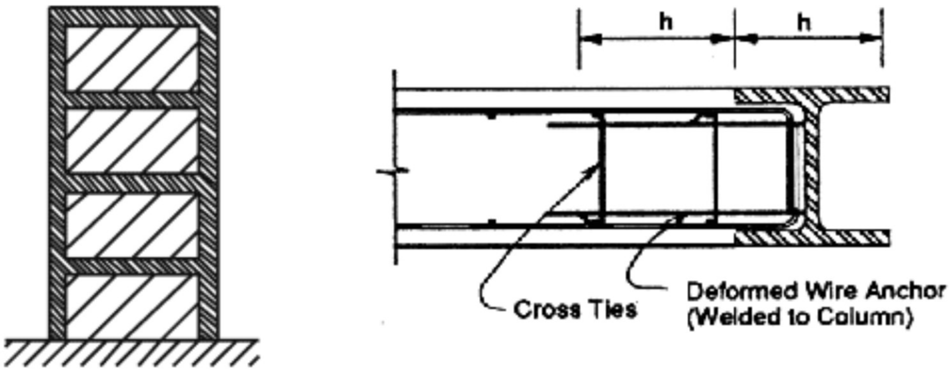

Figure 6. C-SRCW structural system, as recognized by AISC and Eurocode 8

As supported by AISC Seismic Provision 2005, columns in this system can be whether non-encased or encased steel columns. In the case of non-encased columns, mechanical connectors, such as headed studs or channels, are required to transfer vertical shear between the wall and column, and to anchor the wall reinforcements.

If the wall elements are interrupted by steel beams, shear connectors are needed at the wall to beam interface.

Specification of this system can be found in some codes of practice, important provisions of this system according to AISC seismic provision part II, Sec. 15 and 16 are as follows,

1. The wall in this system should be designed according to ACI318 including Chapter 21, i.e. special reinforced shear wall. Effective flexural rigidity of the concrete wall should be multiplied by 0.7 according to ACI318 (Sec. 10.10.4.1). However according to FEMA356, flexural and shear rigidities of the wall should be multiplied by 0.8 and 0.4, respectively. As a result, flexural rigidity of the wall is multiplied by 0.7 according to ACI318 and its shear rigidity is multiplied by 0.4 according to FEMA356, in the current manuscript.
2. When un-encased structural steel sections (columns) acts as boundary members, the required axial strength of the boundary members should be determined assuming that the shear forces are carried by the reinforced concrete wall and the entire gravity and overturning forces are carried by the boundary members in conjunction with the shear wall.
3. AISC provide no provision for the beam frames two vertical columns in this section. These beams would increase web crushing strength of the wall.
4. Capacity of shear connectors should be decreased by 25%. This reduction factor considered to be 40% for shear connectors of the steel beams because according to the results reported by Tong *et al* (2005) these shear connectors are more vulnerable to failure. ***(Tong X., Hajjar JF., Schultz AE., Shield CK. (2005), "Cyclic behaviour of steel frame structures with composite reinforced concrete infill walls and partially-restrained connections," Journal of Constructional Steel Research 61, 531-552.)***

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5. Connection of the steel beam to steel column can be pinned according to ASCE7 definition for this system. However, partially restrained connection as suggested by Tong *et al* (2005) is more preferable because in this scheme additional energy can be dissipated through plastic rotation of the PR connections. Infilled panel dramatically decrease demand of the steel beam such that there is no need to fully restrained connections. Besides lighter sections can be adopted for the steel beam. To use advantages of the above techniques in this manuscript light steels sections are adopted for the beams and full-restrained connections are provided for them.

Adopted design procedure of C-SRCW system is as follows,

Step1*. The bare frame would be designed for gravity loads.*

Distribution of gravity loads should be such that steel frames (beams and columns) of CSRCW system can be as light as possible. It should be noted that using very strong columns as the boundary members is not a wise proportion because the web crushing of the infilled panel would be the dominate failure mechanism in this case which is not a ductile mechanism.

Step2*.*

Infilled panels (considering cracked stiffness) would be implemented into the model and then the whole structure (steel elements and concrete panels) would be controlled for load combinations including full seismic loads. All shear loads of the C-SRCW frame should be resisted by infill panels and axial loads due to overturning should be resisted by both boundary columns and infilled walls.

It should be noted that the above procedure is a conservative design scheme due to the fact that according to AISC-05m Sec. 15.2, the first step is not mandatory.

SMF=special moment frame (ductility would be provided by plastic flexural hinges in beams and column base).

EBF= eccentrically braced frame (ductility would be provided by plastic shear hinges in link beam)

SCBF= special concentrically braced frame (ductility would be provided by plastic flexure-compression hinges at the braces under compression and yielding on the braces under tension).

C-SRCW=special reinforced concrete shear wall composite with steel elements (ductility would be provided by tension yielding and compression-flexure plastic hinges on the boundary steel columns)

Case I (SYSCERA)

According to architectural plans of the building,

X-direction: SMF+ SCSW+EBF R=7, Cd=5.5, Ω=2.5 (height limit in D seismic category = not limited)

Y-direction: C-SRCW + SMF R=7, Cd=6, Ω=2.5 (height limit in D seismic category = not limited)

It should be noted that SYSCERA walls can be considered as special shear walls. The term "special" indicates high ductility of special shear walls. According to finite element models of SYSCERA walls, using Abaqus, SYSCERA walls are quite ductile even more than ACI requirements (see Appendix A).

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Case II

According to a report created by EVG3D®, which is one of the greatest 3D panel producers, the minimum thickness of concrete is 5cm in 3D panel walls intended to be load-bearing walls, except for one-story buildings that the thickness is limited to 4cm. This is mainly due to the fact that for smaller thickness the concrete sheer of the wall is buckle prone.

The shear strength of 3D panel walls is provided by diagonal truss-like bars of the panel. Shear capacity, therefore, is limited to buckling strength of diagonals and by their welding strength. Due to the fact that these diagonals are embedded into EPS core, they have a great potential for buckling. These buckling is observed in some experimental studies such as those carried out by Kabir (2005), and Rezaifar et al (2009). The latter study is experimental shaking table study that shows a pinched form for hysteresis curves of 3D panel walls; however, this pinching is not mentioned explicitly in that paper.

Accordingly, 3D panel walls cannot be considered as special walls due to their potential for buckling both in concrete sheets and in their diagonals. However, it is allowable to consider them as ordinary reinforced walls.

Due to aforementioned reasons 3D panel walls are not considered as structural elements in the current study. Therefore, the following systems are adopted as structural systems of the building.

X-direction: SMF+EBF, R=8, Cd=4, Ω=2.5 (height limit in D seismic category = not limited)

Y-direction: SCBF, R=6, Cd=5, Ω=2 (height limit in D seismic category = 160ft or 49m)

Case III

According to architectural plans of the building, special moment resisting frame plus eccentric braced frames can be adopted for X-direction.

For Y-direction, special steel concentrically braced frames are adopted.

According to Table 12.2-1 of ASCE7-05,

X-direction: SMF+EBF, R=8, Cd=4, Ω=2.5 (height limit in D seismic category = not limited)

Y-direction: SCBF, R=6, Cd=5, Ω=2 (height limit in D seismic category = 160ft or 49m)

It is interesting to note that in this case, according to Standard No. 2800,

Cx=0.067, Cy=0.112

Meanwhile, according to ASCE7-05,

Cx=0.069, Cy=0.136

It is quite clear that both codes lead to approximately equal results. However, ASCE7-05 is a little more conservative.

3D views of all three cases are depicted in Figures 7 and 8.

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It should be pointed out that in all cases it was assumed that backfill soil behind the basement cannot impose any noticeable constraint for lateral displacement of the building.

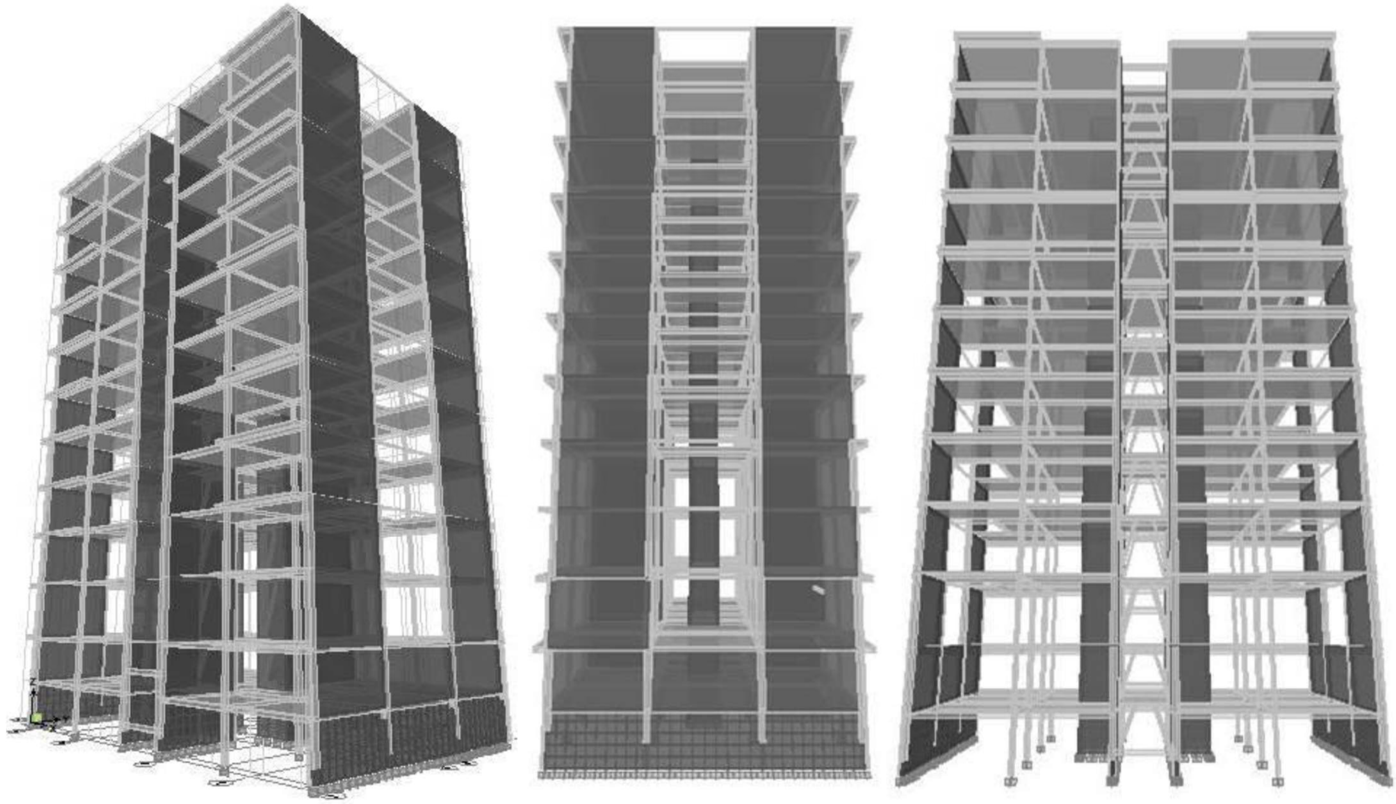

Figure7. Figure7. 3D view of Case I (SYSCERA)

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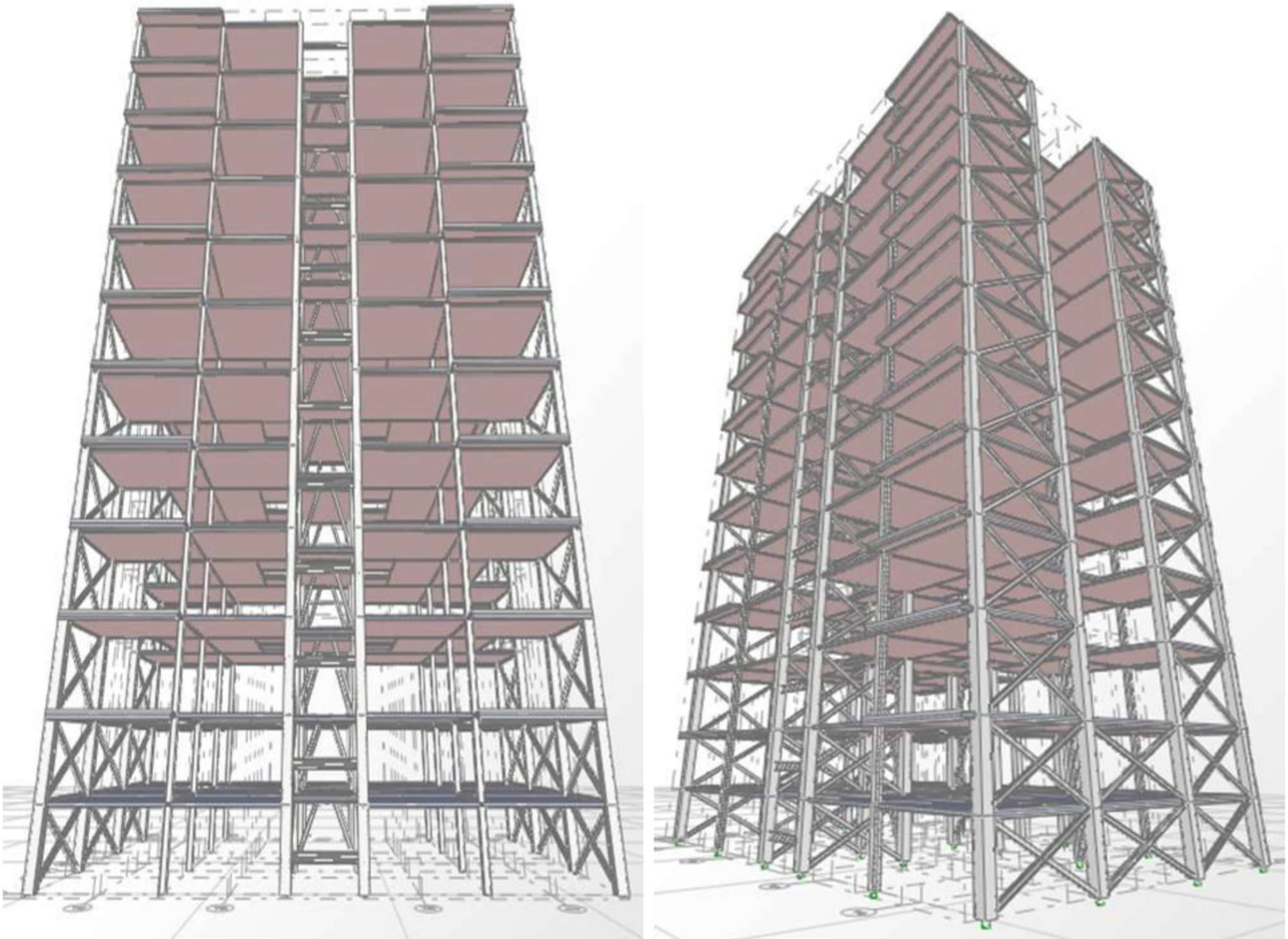

Figure8. 3D view of Cases II and III

Stability Analysis

The stability analysis is carried out using Direct Analysis Method (DAM) according to AISC-05 (Appendix 7). In this method effective length factor (K) equals to unity in all cases. This method includes,

Flexural, shear, and axial deformation+ stiffness reduction due to inelasticity+ geometric imperfection+ a rigorous non-linear p-delta analysis that accounts for local p-delta effects.

Small P-delta, i.e. P- δ , could be accounted by dividing all frame members into two elements, using auto mesh technique.

It is interesting to note that effective length method assumes all columns buckle simultaneously which is a very conservative assumption that does not represent the actual behaviour of the structure, as supported by CSI Steel Frame Design Manual (2009).

Response Spectrum Scaling

Adopted spectrum is scaled per ASCE7-05 (Sec. 12.9.4).

Obtained results

Results of all considered cases are summarized in Table3.

Table 3. Results of adopted cases

Case	TD (ton)	TL (ton)	V_x (ton)	V_y (ton)	Total steel weight (ton)	Steel weight (Kg/m^2)	T_x(s)	T_y(s)
I	1935	965	143	239	165	42	2.15	1.07
II	2320	965	152	298	250	64	1.46	1.02
III	3010	965	223	390	297	76	1.75	1.17

TD = Total Dead Load, TL = Total Live Load, Vx = Seismic Base Shear in X Direction, Vy = Seismic Base Shear in Y Direction, T = Natural Period of the Building

Is SYSCERA System Cost Effective?

In order to address the above question, costs of each case are evaluated in this section using the following reasonable assumptions,

It should be pointed out that costs of finishing and flooring are not included in Table4.

It is worth noting that 1200 Tomans (Iran) is roughly 1 US.$.

Table4. Estimated costs for each square meter

Item	Cost (Thousand Toman/m^2)
Mini-Beam floor	40
SYSCERA wall	35 (Iranian SYSCERA panel)-50(imported SYSCERA panel)
3D panel wall	30
3D panel floor	35
Hollow brick wall	24
joist-block floor	33

Cost of the product (milliers Toman / m2)

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Cost of steel structure assumed to be 1600 Tomans/Kg. (The real cost is lower than the mentioned value, but it is increased by 15% to reflect additional costs due to structural connections.)

It should be noted that the area of floors is 3900m2 and the area of all walls is 5950m2.

(Finishing, flooring, façade, and mechanical-electrical facilities are disregarded)

But are taken into account for SYSCERA,

Since the second work is installed inside the SYSCERA structures before the concrete is injected into these structures.

Table5. Costs comparison between different cases in Million Tomans (Iran)

Case	Steel Frame (Million Tomans)	Walls (Million Tomans)	Floors (Million Tomans)	Total (Million Tomans)
I (Iranian SYSCERA panel)	264	208	156	628
I (Imported SYSCERA panel)	264	298	156	718
II	400	179	137	716
III	475	143	129	747

Or Simply,

Table6. Total cost comparison

Case	Cost (Thousand Toman/m^2)
I (Iranian SYSCERA panel)	161
I (Imported SYSCERA panel)	184
II	183
III	192

The author would like to clarify that due to low gravity loads in Case I, sizes and costs of foundation of the building would be smaller than other cases. This reduction, however, is not addressed in the current manuscript.

Above results justify using SYSCERA system in high-rise buildings according to economical point of view.

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Conclusion

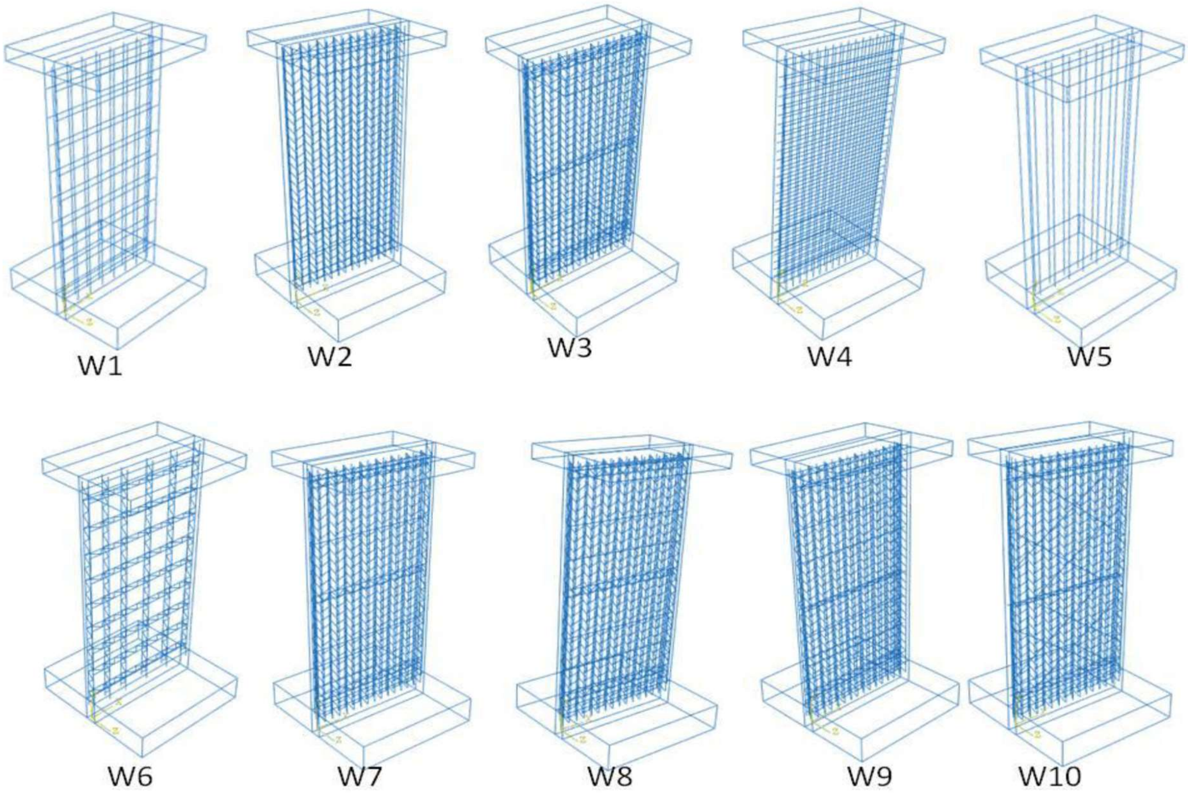
According to this manuscript, it is found that SYSCERA system can be used both as structural and partition walls. Due to its lightness and load bearing capacity, SYSCERA system dramatically reduces structural member sizes. SYSCERA walls are light enough to effectively reduce imposed seismic loads, and ductile enough to noticeably dissipated in putted seismic energy.

Appendix A: Behaviour of SYSCERA walls

Real behaviour of SYSCERA walls has been investigated earlier by the author and it was found that they are quite ductile whether slender SYSCERA wall or squat SYSCERA wall.

Part a. Slender Walls

10 different slender walls, as shown in Figure A.1 are considered and subjected to monotonic in pa-lateral displacement. Their capacity curves are illustrated in Figures A.2 and A.3.



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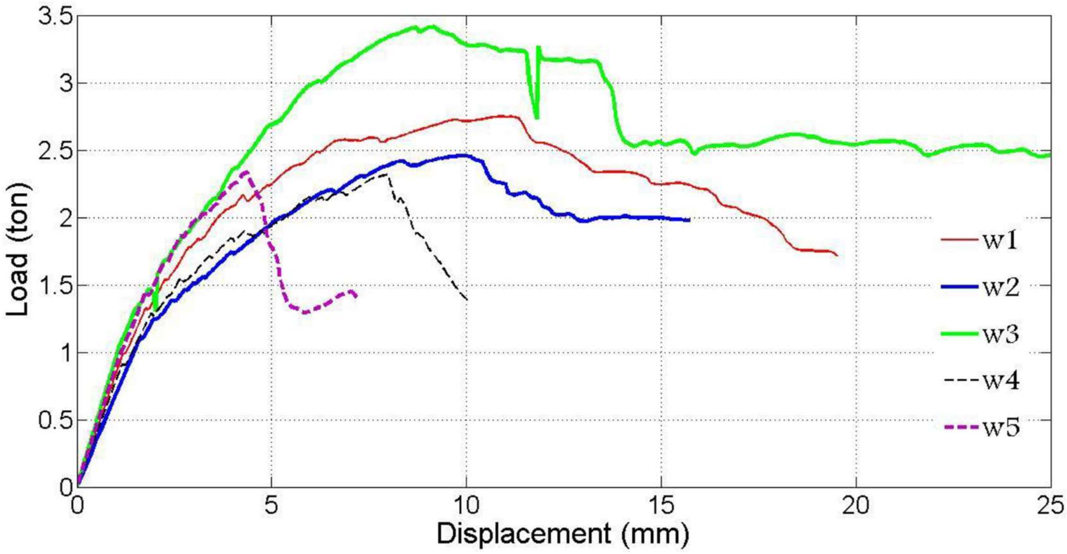

Figure A.2

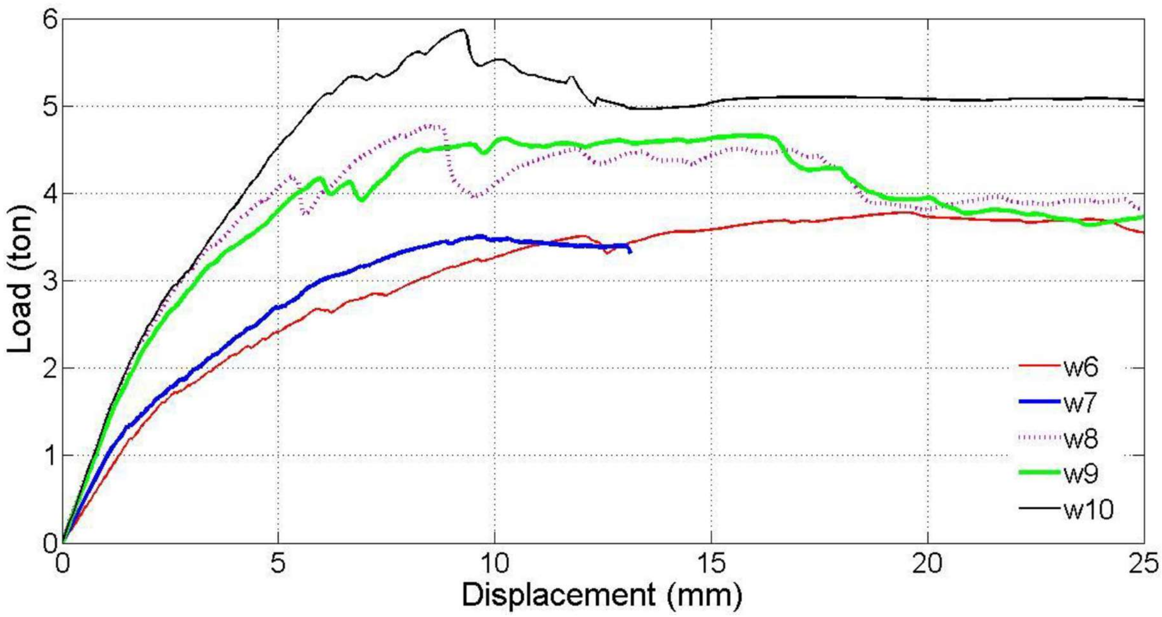

Figure A.3

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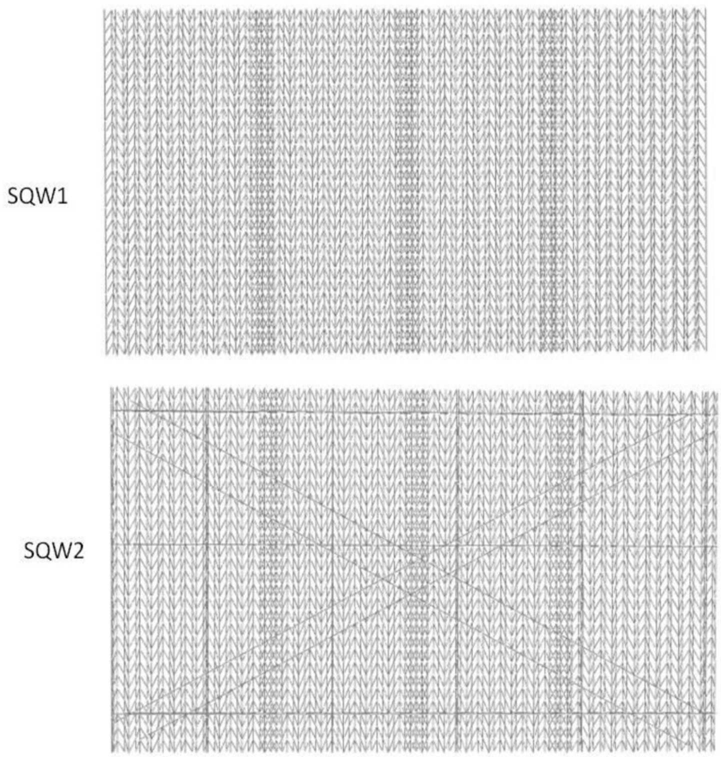
Part b. Squat Walls

Two different cases are considered here, as depicted in Figure A.4. Case SQW1 is a squat wall reinforced with SYCERA panels. And SQW2 is the same wall reinforced with SYSCERA panels, SYSCERA beams, and diagonal rebars.



rebars.

Figure A.4

Capacity curves of these cases would be as shown in Figure A.5.

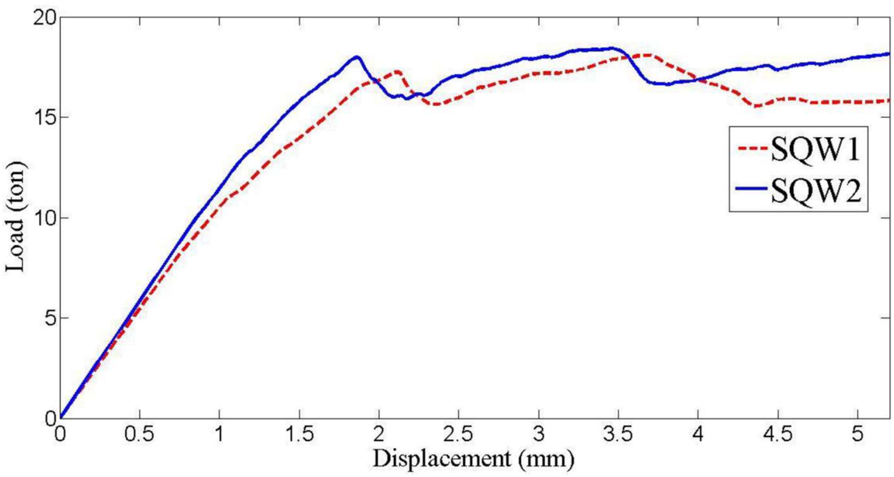


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Figure A.5

Conclusions of Oristeel France:

1. OriSTeeL France logically concluded that the W3 and W10 solutions in table A1 are the two most relevant solutions for building high-rise buildings with the OriSTeeL TD8 structures used in SYSCERA constructions, such as the shows the curves of tables A2 and A3

2. All the modulations and calculations of this dossier were carried out on the basis of SYSCERA walls of a thickness of 12cm or everything, with metal structures unfolded 8cm thick, corresponding to the standard TD8 of OriSTeeL France, see Figure 4. EPS concrete has a density of about 1000Kg/M3.

3. In 2019, OriSTeeL offers tools and machines that can produce metal structures of 8, 12, or 16cm thick, for gold walls of 14, 18, or 22cm thick, and a lightweight concrete of 1100Kg/M3.

4. These new products offered by OriSTeeL France reinforce and increase the capabilities of the SYSCERA system to withstand earthquakes and provides a definitive response regarding high-rise constructions.

5. It is therefore evident that with this system, the construction of high-rise buildings, type 12 storeys or more, is validated as part of a use with porous beams, in accordance with the example described in this the file

6. The engineers who developed all the calculations presented here participated in the 3rd National Conference on earthquakes and their structure, 17-18 October 2012, CECRC de Kerman, Kerman, Iran. Iran is one of the countries in the world most frequently affected by violent earthquakes, it is a country far ahead of scientific research related to these natural phenomena.

7. With the new improvements made to the metal structures by OriSTeeL France in the last two years (2017 and 2018), allowing seamless interconnection and continuity in the new metal structure locking system OriSTeeL between them, the performance demonstrated here will be further improved. For example, the use of mini head studs to transfer the vertical shear between the different elements of the building, mainly at the level of the vertical walls. Under certain circumstances, these mini studs may be used as a fuse in the event of a violent earthquake, without necessarily causing additional damage to the structure.

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